Distributed Air/Ground Traffic Management Concept Elements 5, 6, and 11 Technology and Concept Demonstration Report

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Executive Summary

In September 2001, the Distributed Air/Ground Traffic Management (DAG-TM) research team at the NASA Ames Research Center in Mtn. View, CA conducted a Technology and Concept Demonstration. The demonstration encompassed three of the original AATT, DAG-TM concepts – CE5, CE6, and CE11 – in a virtual operating environment which included controllers, pilots, and simulation support personnel, making use of three separate facilities – the Airspace Operations Laboratory (AOL), Flight Deck Display Research Laboratory (FDDRL), and Crew Vehicle Systems Research Facility's (CVSRF), Advanced Concepts Flight Simulator (ACFS) – along with an array of existing and concept-specific Decision Support Tools (DSTs) and novel procedures.

Dallas airport and surrounding en route airspace was used. Participant controllers monitored and then transitioned free flight aircraft into controlled airspace, data-linked route and clearance information, and sequenced them for approach and landing, using Center TRACON Automation System DSTs. Pilot participants flew the ACFS, solved route conflicts in free flight airspace, data-linked route changes to air traffic controller for approval in some instances, and spaced on a lead aircraft during the approach phase, using an enhanced Cockpit Display of Traffic Information. Two pilots and four controllers participated in the study. The study involved four scenarios: CE5 Easy, CE 5 Difficult, CE 6 Easy, and CE 6 Difficult. The easy and difficult scenarios differed in traffic density; the difficult scenario had higher traffic density than the easy scenario. Both CE 5 and CE 6 operations involved free maneuvering but CE 6 operations required that pilots inform the controllers of their intent prior to maneuvering. The data was collected using questionnaires and debriefings.

The demonstration indicated that concepts have potential to increase flexibility and capacity and to be operationally feasible. The test environment was proven to be robust and offered useful architecture for more advanced research in the future. The participant feedback provided valuable insight into the continued development of DSTs and procedures that will help guide the direction and refinement of future research.

1 Document Purpose

This document describes the background, objectives, procedure, data collection, and overall findings of the Distributed Air/Ground Traffic Management (DAG-TM) technology and concept demonstration conducted at the NASA Ames Research Center in September 2001.

2 Background

NASA's DAG-TM represents a paradigm shift, which will bring changes to the roles and responsibilities of air traffic service providers (ATSPs), traffic flow management (TFM) specialists, flight crews (FCs), and Airline Operations Center (AOC) specialists. The DAG-TM project contains 15 concepts covering all phases of flight.

The current program priorities include:

- CE 5 En Route Free Maneuvering,
- CE 6 En Route Trajectory Negotiation, and
- CE 11 Terminal Arrival Self-Spacing.

Accordingly, the September 2001 concept demonstration encompassed CE 5, CE 6, and CE 11 operations. Each of these concept elements is described below. The descriptions are taken from the original Advanced Air Transportation Technologies (AATT) DAG-TM concept document (AATT, 1999), and the detailed concept definition documents for CE 5, CE 6, and CE 11 prepared by Phillips (2001), Couluris (2001), and Sorensen (2001) respectively.

2.1 Description of CE 5-En Route: Free Maneuvering for User-preferred Separation Assurance and Local TFM Conformance

It is noted that this concept element applies to all phases of flight (departure, cruise and arrival) in the operational domain of en route airspace.

2.1.1 Current Problem

(a) ATSP often responds to potential traffic separation conflicts by issuing trajectory deviations that are excessive or not preferred by users.

In the current air traffic control (ATC) system, trajectory prediction uncertainty leads to excessive ATC deviations for separation assurance. Due to workload limitations, controllers often compensate for this uncertainty (which may be equivalent to or greater than the minimum separation standard) by adding large separation buffers for conflict detection and resolution (CD&R). Although these buffers reduce the rate of missed alerts, some aircraft experience unnecessary deviations from their preferred trajectories due to the unnecessary resolution of false alarms (i.e., predicted conflicts that would not have materialized had the aircraft continued along their original trajectories). In those cases where a potential conflict really does exist, the buffers lead to conservative resolution maneuvers that result in excessive deviations from the original trajectory. Moreover, the nature of the resolution (change in route, altitude, or speed) may not be user-preferred. Due to a lack of adequate traffic, weather, and airspace restriction information (and the means to present such information), and also a lack of conflict resolution tools on the flight deck, current procedures generally do not permit the user to effectively influence controller decisions on conflict resolution.

(b) ATSP often cannot accommodate the user's trajectory preferences for conformance with local TFM constraints.

The dynamic nature of both aircraft operations and NAS operational constraints often result in a need to change a 4-D trajectory plan while the aircraft is en route. Currently, the user (FC or AOC) is required to submit a request for a trajectory change to the ATSP for approval. During flow-rate constrained operations, the ATSP is rarely able to consider user preferences for conformance. Additionally, a lack of accurate information on local traffic and/or active local TFM constraints (bad weather, special use airspace [SUA], airspace congestion, arrival metering/spacing) can result in the FC or AOC requesting an unacceptable trajectory. The ATSP is forced to plan and implement clearances that meet separation and local TFM constraints, but may not meet user preferences. Further negotiation between the ATSP and FC can adversely impact voice-communication channels and increase ATSP and FC workload.

2.1.2 Solution (Flight Deck Focus)

(For both a and b, above) Appropriately equipped aircraft accept the responsibility to maintain separation from other aircraft, while exercising the authority to freely maneuver in en route airspace in order to establish a new user-preferred trajectory that conforms to any active local TFM constraints.

While in the en route operational domain, appropriately equipped aircraft are given the authority, capability, and procedures needed to execute user-preferred trajectory changes without requesting ATSP clearance to do so. Along with this authority, the flight crew takes on the responsibility to ensure that the trajectory change does not generate near-term conflicts with other aircraft in the vicinity. The trajectory change should also conform to any active local TFM constraints (bad weather, SUA, airspace congestion, arrival metering/spacing). User-preferred trajectory modification may be generated by the FC with AOC input if appropriate, or generated entirely by the AOC and transmitted to the FC via datalink. The FC broadcasts its modified flight plan via datalink (includes notification of ATSP) immediately after initiation of trajectory modification; in most situations, this task is handled by on-board automation.

The ATSP monitors separation conformance for free maneuvering aircraft, and provides separation assurance for lesser-equipped aircraft using CD&R decision support tools (DSTs). The ATSP may act on behalf of lesser-equipped aircraft when they are in potential conflict with free maneuvering aircraft. For cases where the flight crew attempts, and fails, to resolve a conflict, automated systems or the ATSP will provide a required resolution. Procedures and flight rules are established that provide incentive for aircraft to equip for self-separation, such as, perhaps, priority status in conflicts with lesser-equipped aircraft.

2.1.3 Potential Benefits of CE 5 Operations

- Reduction in excessive and non-preferred deviations for separation assurance and local TFM conformance, due to the ability of the flight crew (for equipped aircraft) to self-separate and maintain local TFM conformance according to their preferences.
- Increased safety in separation assurance for all aircraft, due to communications, navigation, and surveillance redundancy (FC as primary and ATC as backup) and increased situational awareness of the FC of appropriately equipped aircraft.
- Reduced ATSP workload for separation assurance and local TFM conformance plus reduced flight crew workload for communications, due to the distribution of responsibility for separation assurance and local TFM conformance between the ATSP and appropriately equipped FCs.

2.2 Description of CE 6-En Route Trajectory Negotiation

2.2.1 Problem Description

These descriptions address ATSP problems in fully accommodating user preferences as determined by aircraft FC and AOC trajectory assessments and plans. As stated in the concept definition for DAG-TM:

(a) ATSP often responds to potential traffic separation conflicts by issuing trajectory deviations that are excessive or not preferred by users.

In the current ATC system, trajectory prediction uncertainty leads to excessive ATC deviations for separation assurance. Due to workload limitations, controllers often compensate for this uncertainty (which may be equivalent to or greater than the minimum separation standard) by adding large separation buffers for CD&R. Although these buffers reduce the rate of missed alerts, some aircraft experience unnecessary deviations from their preferred trajectories due to the unnecessary resolution of false alarms (i.e., predicted conflicts that would not have materialized had the aircraft continued along their original trajectories). In those cases where a potential conflict really does exist, the buffers lead to conservative resolution maneuvers that result in excessive deviations from the original trajectory. Moreover, the nature of the resolution (change in route, altitude or speed) may not be user-preferred. Due to a lack of adequate traffic, weather, and airspace restriction information (and displays), and also to a lack of conflict resolution tools on the flight deck, current procedures generally do not permit the user to effectively influence controller decisions on conflict resolution.

(b) ATSP often cannot accommodate the user's (FC or AOC) trajectory preferences for conformance with local TFM constraints.

The dynamic nature of both aircraft operations and NAS operational constraints often result in a need to change a 4-D trajectory plan while the aircraft is en route. Currently, the user (FC or AOC) is required to submit their request for a trajectory change to the ATSP for approval. During flow-rate constrained operations, the ATSP is rarely able to consider user preferences for conformance. Additionally, a lack of accurate information on local traffic and/or active local TFM constraints (bad weather, SUA, airspace congestion, arrival metering/spacing) can result in the FC or AOC requesting an unacceptable trajectory. The ATSP is forced to plan and implement clearances that meet separation and local TFM constraints, but may not meet user preferences. Further negotiation between the ATSP and FC can adversely impact voice-communication channels and increase ATSP and FC workload.

2.2.2 Solution Description

(a) Reduce unnecessary and/or excessive ATSP-issued route deviations for traffic separation by enhancing ATSP trajectory prediction capability through user-supplied data on key flight parameters.

The user (FC and/or AOC) will provide information via datalink on key parameters such as aircraft weight, trajectory intent (route, altitude, and speed profile), local winds/temperature aloft, and navigational performance. The provision of this information will not adversely affect FC and/or AOC workload, and will be automated. An ATSP-based decision support tool (DST) will use this data to improve its trajectory predictions, resulting in improved CD&R performance. This improvement will: (1) Reduce the number of unnecessary conflict resolution maneuvers by decreasing the conflict prediction false-alarm rate; and, (2) Reduce the extent of excessive trajectory deviations for conflict resolution by decreasing the uncertainty in future positions of the aircraft.

Appropriately equipped users will be able to submit their preferences for resolving conflicts. These preferences may include (but are not limited to): a specified 4-D trajectory; a specified route, and/or altitude and/or speed profile; or, preferred degree(s)-of-freedom (route, altitude, speed) for conflict resolution. The trajectory negotiation process may involve single-flight collaboration between the ATSP and an individual user, or multiple-flight collaborations between the ATSP and multiple users for determining a balanced set of deviations among a group of flights. Following the selection of a conflict-resolution plan, the ATSP then transmits (via datalink) the conflict-free trajectory solutions to the appropriately equipped aircraft for execution (thereby further reducing trajectory uncertainty and subsequent conflict false-alarm and missed-detection rates). It is emphasized that the ATSP retains full responsibility for separation assurance.

(b) Facilitate trajectory change requests for en route aircraft by providing the user (FC and/or AOC) the capability to formulate a conflict-free user-preferred trajectory that conforms to any active local-TFM constraints.

By making use of information on local traffic and TFM constraints, the user is able to formulate intelligent trajectory change requests that are likely to be acceptable to the ATSP and therefore less workload-intensive for the ATSP to evaluate and coordinate. Using datalink, the AOC transmits relevant information on airline preferences/ constraints to the FC. The flight crew uses a FC-based trajectory planning DST to compute a conflict-free user-preferred trajectory that conforms to any active local TFM constraints (bad weather, SUA, airspace congestion, arrival metering/ spacing). The FC transmits the desired trajectory to the ATSP via datalink. The ATSP uses their DST to review the request, and in most cases, finds the request acceptable and issues a clearance for the new trajectory. If the request is not acceptable, the ATSP denies the request and may use their DST to formulate an alternative clearance or provide additional information on ATSP requirements/ constraints. It is emphasized that the ATSP retains full responsibility for separation assurance.

2.2.3 Potential Benefits of CE 6 Operations

- Reduction in excessive deviations for separation assurance, due to improved CD&R capabilities of ATSP-based DSTs, enabled by user-supplied data on key flight parameters.
- Reduction in non-preferred deviations for separation assurance, due to user-ATSP collaboration for conflict resolution maneuvers.
- Increased ATSP accommodation of user requests for trajectory changes, due to the user's ability to intelligently formulate trajectory change requests that conform to local traffic and TFM constraints.
- Reduced ATSP workload, due to improved CD&R capabilities (enabled by user-supplied data) for separation assurance, and intelligent user requests for trajectory changes that conform to local traffic and TFM constraints.

2.3 Description of CE 11-Terminal Arrival: Self-Spacing for Merging and In-Trail Separation

2.3.1 Current Problem

Excessive in-trail spacing buffers in arrival streams reduce runway throughput and airport capacity, especially in conditions of poor visibility and /or low ceilings.

In terminal area environments for which arrival demand approaches or exceeds capacity, aircraft landing rates are significantly lower under instrument meteorological conditions (IMC) than under visual meteorological conditions (VMC). In order to compensate for uncertainties in aircraft performance and position, the ATSP applies in-trail spacing buffers to arrival streams under IMC in order to ensure that minimum separation requirements between successive aircraft are met. The resulting generous arrival spacing reduces runway throughput below its capacity to accept aircraft.

2.3.2 Solution (Flight Deck Focus)

Appropriately equipped aircraft are given clearance to merge with another arrival stream, and/or maintain in-trail separation relative to a leading aircraft.

In VMC, aircraft are often able to maintain closer spacing during the approach, thereby increasing the capacity of the terminal area and the runway acceptance rate. In the current system, the FC is often requested to accept responsibility for visual self-separation once they acknowledge they can see the leading aircraft. In this situation, the FC is responsible for determining and then maintaining a safe separation from other aircraft, and is therefore not subject to the ATSP minimum separation requirements.

Self-spacing operations will enable the FC to autonomously merge with another arrival stream and/or maintain in-trail separation with another aircraft under IMC as they would under VMC, thus significantly increasing arrival throughput. Self-spacing applies to aircraft that are subject to spacing requirements during arrival, from the feeder fix, up to the final approach fix.

Anticipated procedures for self-spacing involve the ATSP transferring responsibility for in-trail separation to properly equipped aircraft, while retaining responsibility for separating these aircraft from crossing traffic. Once the FC receives clearance to maintain spacing relative to a designated leading aircraft, the FC establishes and maintains a relative position with frequent monitoring and speed/course adjustments. Under some conditions, information such as Required Time of Arrival (RTA) at the final approach fix may be provided by an appropriate ATSP-based DST, thereby enabling accurate inter-arrival spacing that accounts for differing final approach speeds or wake vortex avoidance. ATSP monitors all aircraft to ensure adequate separation. For cases where the flight crew fails to maintain adequate spacing, automated systems or the ATSP will provide a required correction.

The self-spacing concept is expected to make use of datalink capabilities to provide position information and a cockpit display of traffic information (CDTI) and/or advanced flight director/heads-up guidance technology to provide spatial and temporal situation awareness to the flight crew. FC-based DSTs will provide information to enable station keeping and/or monitoring of automatic 4-D trajectory management.

2.3.3 Potential Benefits of CE 11 Operations

- Increased arrival capacity/throughput in IMC, due to a reduction in excessive spacing buffers resulting from the ability of appropriately equipped aircraft to operate as if they were in VMC.
- Reduced ATSP workload, due to transfer of separation responsibility to the flight crew of appropriately equipped aircraft.

3 Demonstration Objectives

The goals of the demonstration were to provide for initial instantiation of the necessary technology, and to conduct a preliminary assessment of the feasibility and benefits of CE 5, CE 6, and CE 11 – concepts that include en route free maneuvering and trajectory negotiation, and terminal self-spacing. The specific objectives were as follows:

- Identify procedural, automation, and human factors considerations related to free maneuvering,
- Identify procedural, automation, and human factors considerations related to transitioning between free maneuvering and controlled airspace,
- Identify conflict management issues related to free maneuvering and trajectory negotiation,
- Identify procedural, automation, and human factors considerations related to self-spacing,
- Examine the role of the ATSP within CE 5, CE 6, and CE 11,
- Examine the role of the FC within CE 5, CE 6, and CE 11, and
- Examine the communication needs between the FC and ATSP within CE 5, CE 6, and CE 11.

The procedural considerations focused on the roles and responsibilities, phraseology, and transitions from free flight to controlled flight. The automation considerations focused on information and decision support needs. The human factors considerations included workload, situation awareness, usability, and operational errors.

4 Method

4.1 Participants

Four controllers participated in the study. Two en route controllers were from Oakland Air Route Traffic Control Center (ARTCC), and two terminal area controllers were from Bay Terminal Radar Approach Control (TRACON).

Two commercial airline pilots participated in the study, operating the Advanced Concepts Flight Simulator (ACFS). Pseudo pilots operated all other simulation aircraft.

4.2 Flight Scenarios

The demonstration made use of six different operational flight scenarios: Two were designed for training, and there were four test scenarios including a CE 5 Easy, CE 5 Difficult, CE 6 Easy, and CE 6 Difficult. The easy and difficult scenarios differed only in traffic density, with the difficult scenarios involving more aircraft. All scenarios involved en route and terminal airspace. The CE 5 scenarios used CE 5 procedures in en route airspace and then CE 11 procedures in the terminal airspace. The CE 6 scenarios used CE 6 procedures in en route airspace and then CE 11 procedures in the terminal airspace. In all scenarios, aircraft in free flight were transitioned to controlled, en route airspace prior to entering terminal airspace. The training scenarios were used for concept and procedure familiarization. Figure 1 depicts a conceptual overview of a scenario.

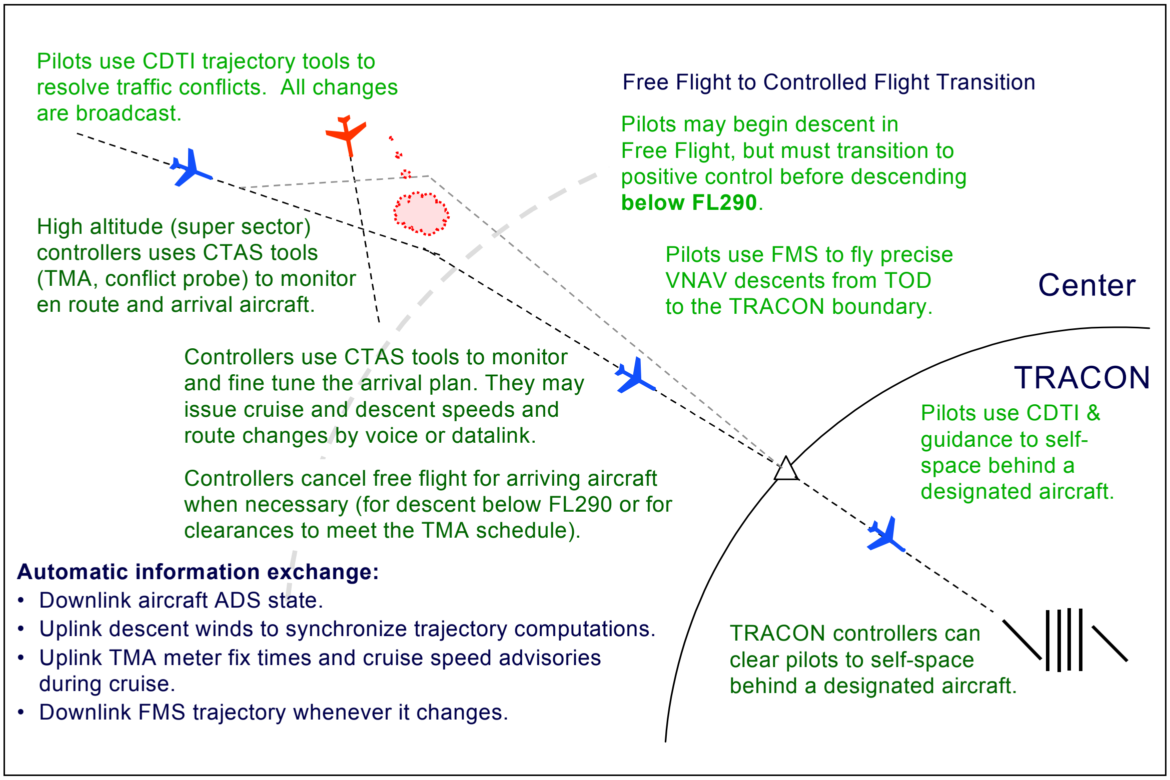

Figure 1. Scenario Overview.

4.3 Airspace Environment

The airspace environment used during the demonstration was Dallas Fort Worth ARTCC (ZFW) sectors and Dallas Fort Worth Airport arrival flow. Figure 2 shows the sector airspace used in the demonstration. This airspace represented ZFW's super high and high altitude sectors. Figure 3 depicts an arrival flow (i.e., Bowie F2) into the airport. Figure 4 shows the approach chart for runway 13R.

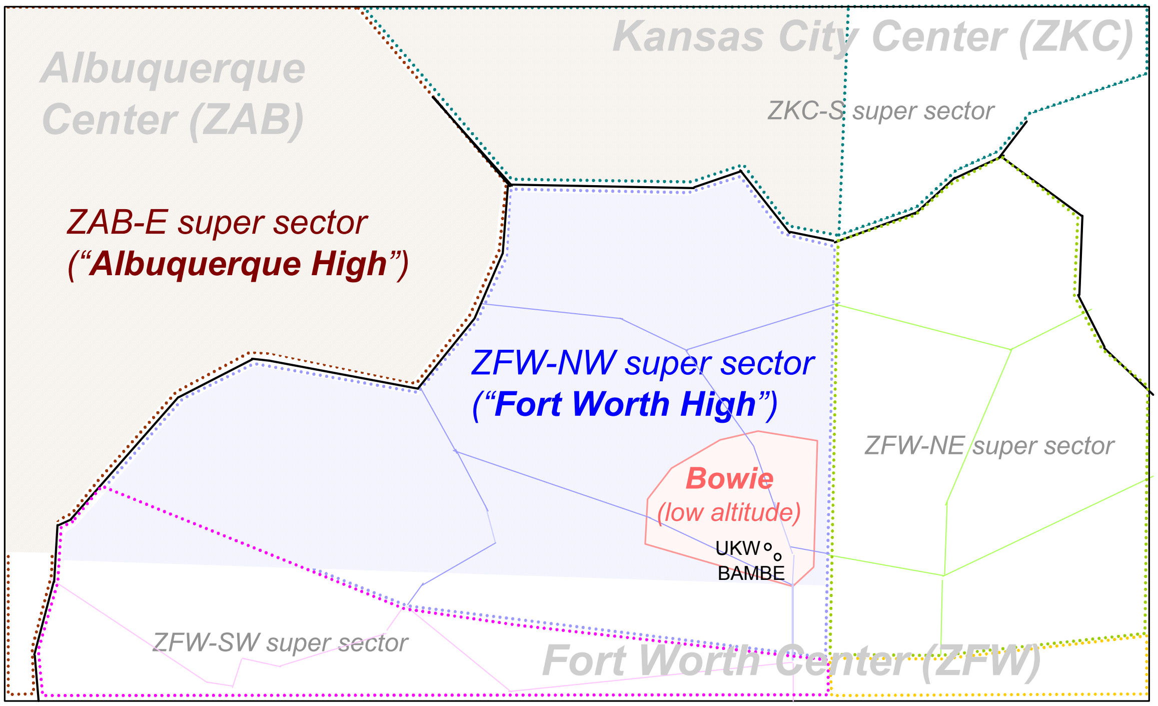

Figure 2. Airspace Environment Represented by the Shaded Area.

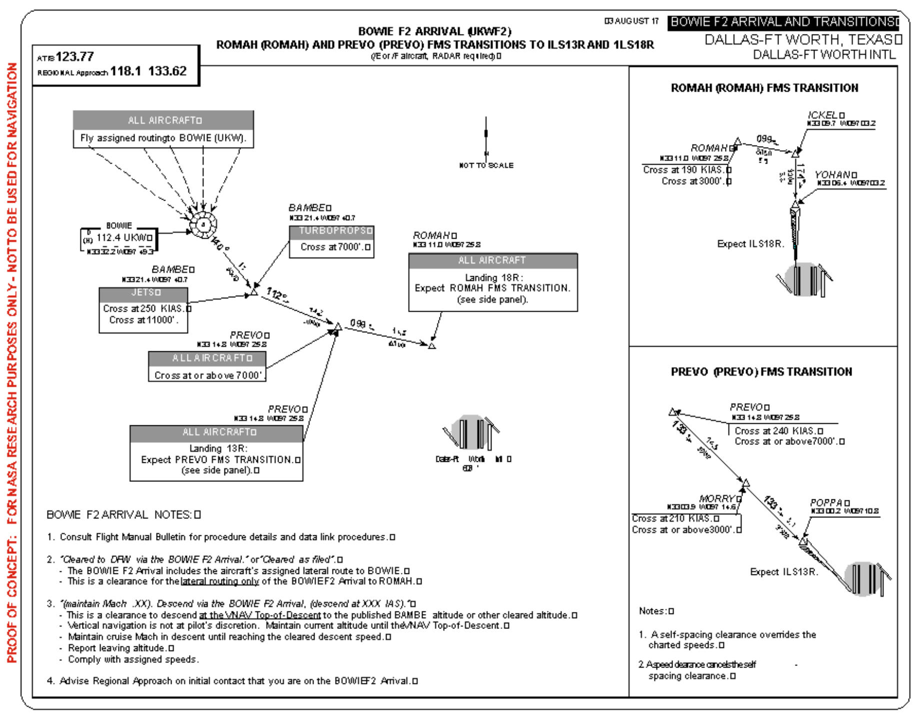

Figure 3. Bowie F2 Arrival Chart.

ILS Rwy 13R Approach Chart

	distance	altitude	speed
BAMBE	41.8nm	11,000'	250
PREVO	27.5nm	7,000'	240
MORRY	13.0nm	3,000'	210
POPPA	7.9nm	3,000'	170
GUUDE	5.4nm	2,300'	150
13R	0.0nm	591'	135

The flying time from BAMBE to Rwy 13R is 609 seconds on the above speed profile

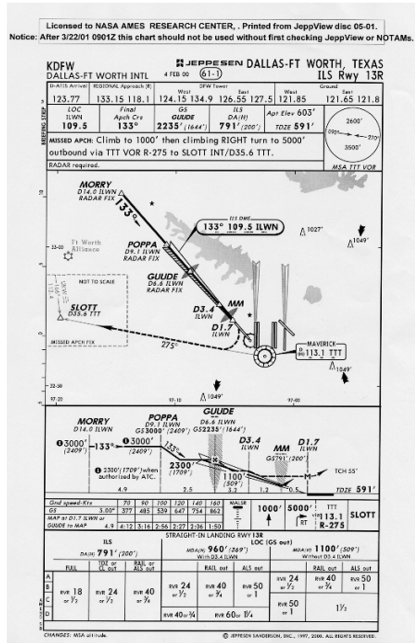

Figure 4. Approach Chart for ILS Runway 13R.

4.4 Assumptions

The following sub-sections detail assumptions related to decision support tool (DST) use, procedures, and roles and responsibilities.

4.4.1 DST Related Assumptions

- All aircraft were datalink equipped, with a CDTI with alerting logic, and a Flight Management System (FMS).
- Aircraft were ***not*** equipped with any RTA capability. However, meter fix RTA advisories, along with cruise speed recommendations could be up-linked to arriving aircraft.

4.4.2 Procedural Assumptions and Operational Rules

- Aircraft at or above FL290 were in free flight, with all aircraft at or below FL280 under positive ATSP control.
- All aircraft needed to be cleared by the ATSP to enter or exit free flight airspace.
- The ATSP could cancel free flight operation at any time.
- Only one party (FC or ATSP) was responsible for separation at any time.
- ATSP had the sole authority to cancel self-separation (free flight).
- Flight crew, upon acceptance, was responsible for separation assurance.
- Flight crew could request ATSP assistance for conflict resolution, flow control, and air traffic management/route considerations.
- Flight crew could ***request*** the cancellation of free flight.

- ATSP provided RTA advisory for meter fix for free flight aircraft but the flight crew was responsible for separation and meeting the RTA clearance above FL290.
- Below FL290, the ATSP was responsible for separation and meeting the meter fix arrival times.
- The flight crew could request a flight plan change at any time.
- The ATSP was instructed to consider user preferences whenever possible.
- In terminal airspace, the flight crew could be cleared to maintain minimum in-trail spacing. However, the ATSP could revoke the self-spacing clearance at any time.

4.4.3 Roles and Responsibilities–En Route Airspace

Free Flight – Controller

In CE 5 scenarios, the ATSP's role involved monitoring sector traffic, and assisting aircraft with weather and ride information. In CE 6 scenarios, the ATSP's role involved monitoring sector traffic, and either approving or disapproving proposed route changes from aircraft. In CE 6 scenarios, the ATSP was responsible for separation and in CE 5 the FC was responsible.

Free Flight – Flight Crew

The FC role involved using the CDTI for route management, navigation, and detection and resolution of conflicts. Each aircraft broadcast their route and any route changes to proximal traffic and to the ATSP. In the CE 5 scenario, the flight crew was not required to obtain prior approval from the ATSP for a route change. In the CE 6 scenario, prior ATC approval to implement a route change was required.

The CDTI presented a conflict alert to the flight crew as the alerting logic detected the potential conflict (see Figure 5).

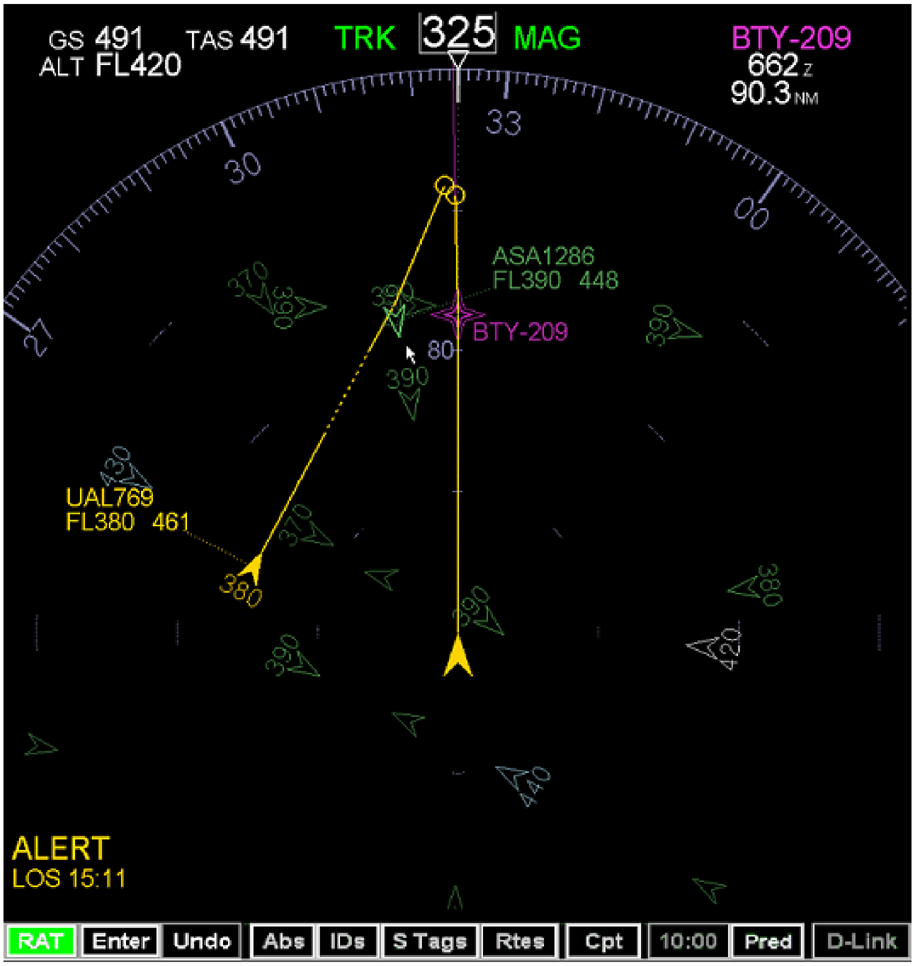

Figure 5. CDTI Displaying a Conflict Alert.

Figure 6 depicts the use of the Route Assessment Tool (RAT) to identify a conflict-free path around the conflicting aircraft.

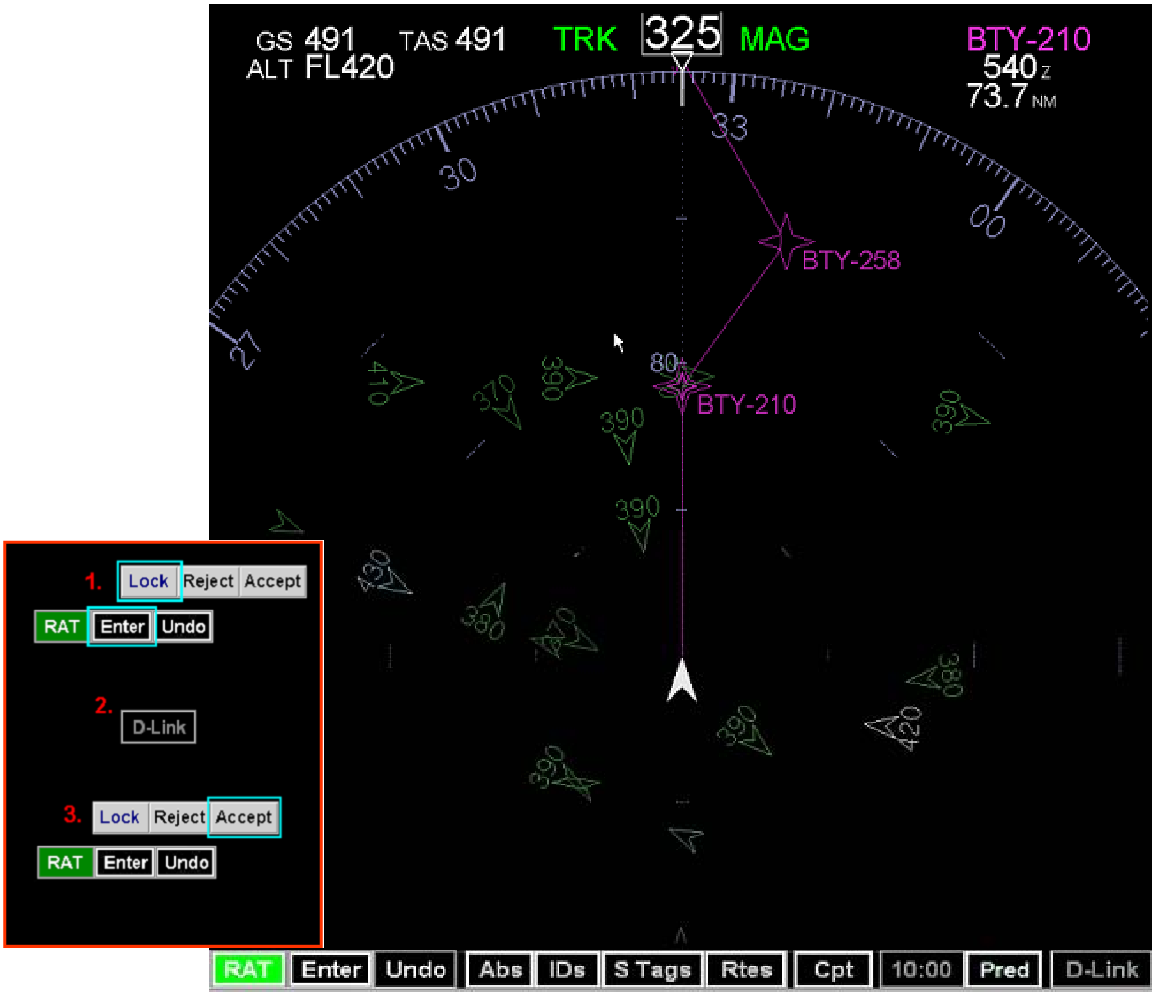

Figure 6. Use of RAT to Determine Conflict-Free Path.

<u>Transition – Controller</u>

The transition controller ended the free flight status for arriving aircraft, reinstating positive control, and prepared aircraft for sequencing and hand-off to the TRACON ATSP.

<u>Transition – Flight Crew</u>

The FC used the CDTI to monitor other aircraft and continued their current flight plan. Once free flight was terminated, the aircraft returned to the positive control of ATSP.

4.4.4 Roles and Responsibilities–Terminal Airspace

Terminal Area - Controller

The en route ATSP delivered aircraft to the BAMBE fix at the TRACON boundary. The TRACON ATSP's role involved clearing aircraft to continue on the PREVO FMS arrival to runway 13R. The TRACON controller cleared aircraft (datalink and/or voice) to initiate self-spacing on a designated lead aircraft, at a specified in-trail time-based value. The ATSP typically used 70 ± 10 seconds for in-trail clearance during the concept demonstration. Figure 7 depicts the self-spacing aircraft as displayed on the TRACON controller workstation.

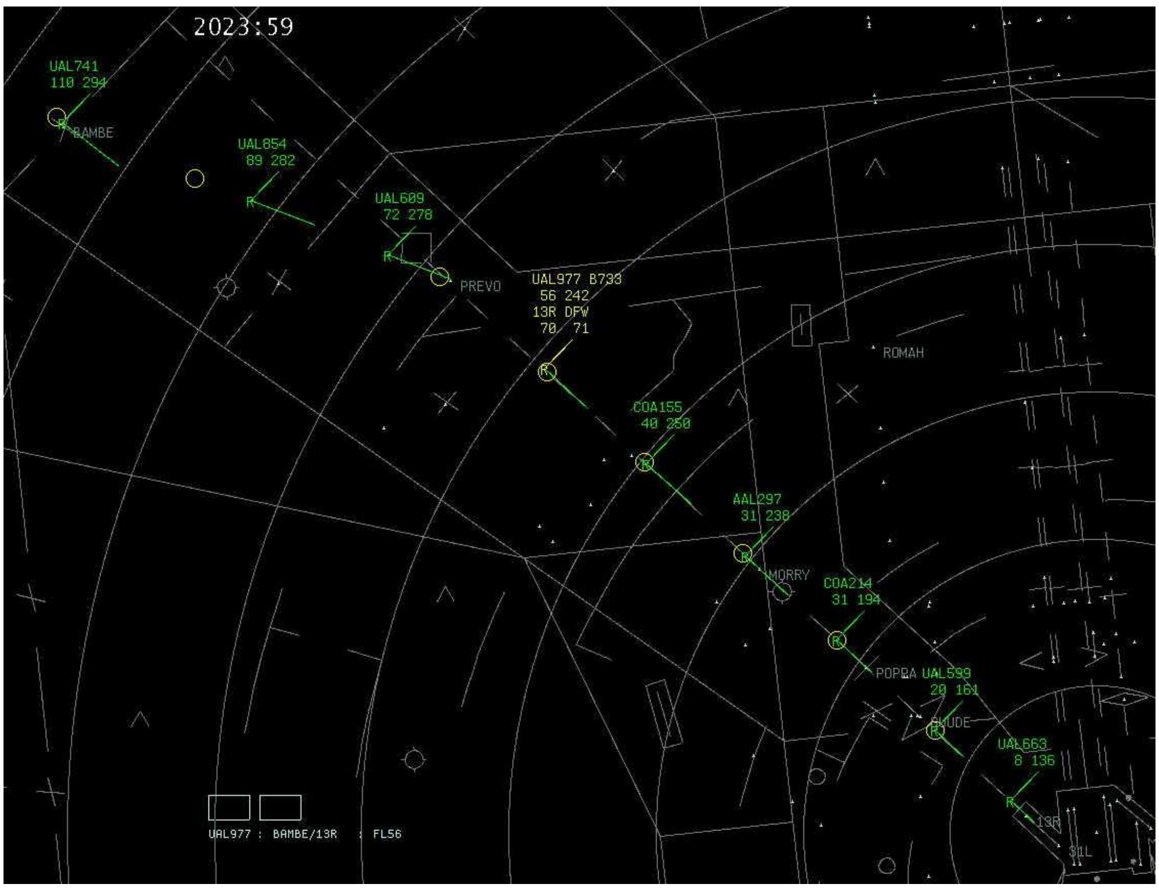

Figure 7. TRACON Controller Display in Self-Spacing Operation.

Terminal Area - Flight Crew

The flight crew's role involved using the CDTI in spacing mode to maintain in-trail position relative to the designated lead aircraft, through descent to the final approach fix.

4.5 Research Environment and Equipment

Figure 8 depicts the DAG technology and concept demonstration architecture. It presents a schematic diagram of different laboratory components that were necessary for this demonstration. Creating this architecture to conduct DAG-TM research was one of the objectives of this demonstration.

Expanding the research environment to incorporate additional participant pilots (and aircraft simulators) and AOC operations is a future task and goal.

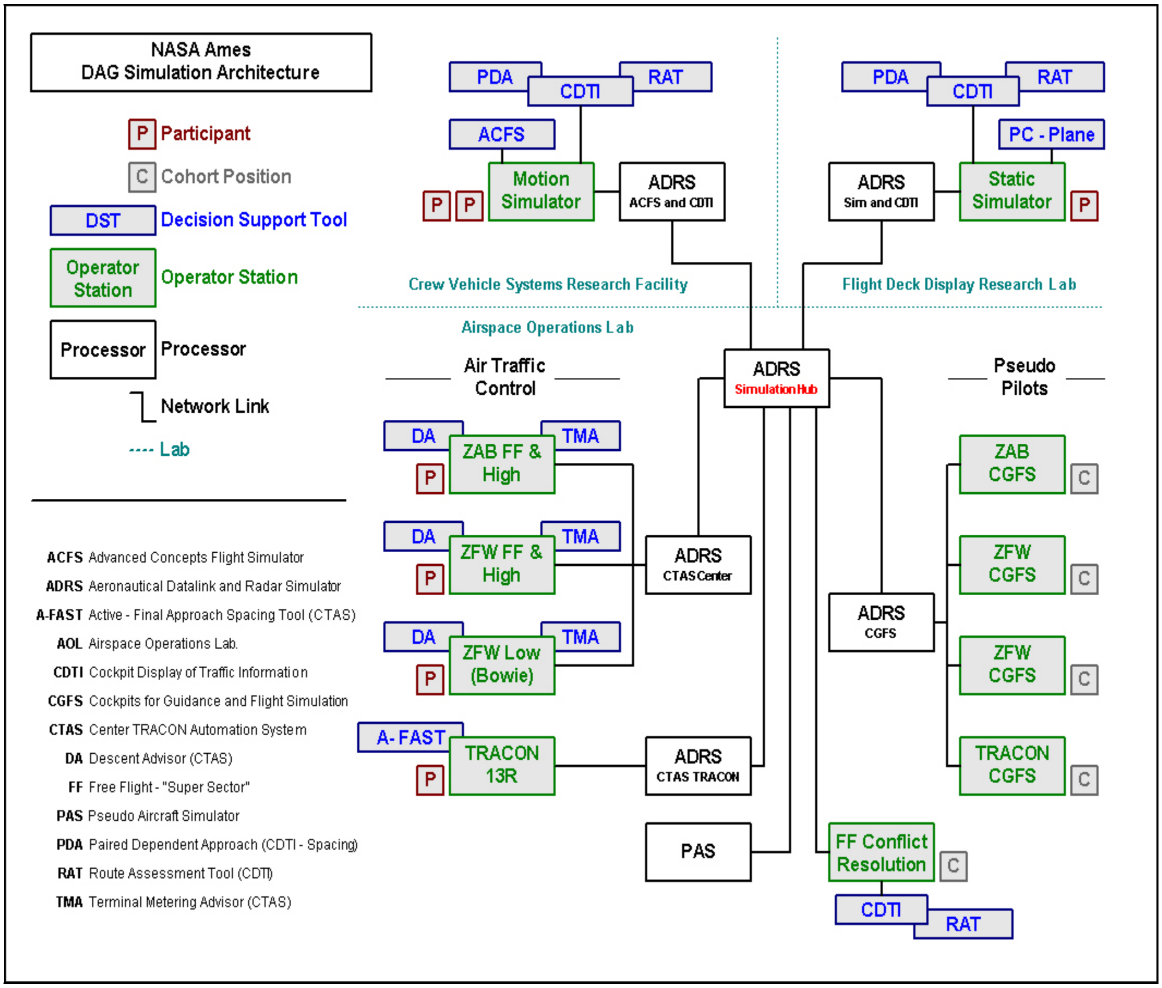

Figure 8. DAG-TM Demonstration Laboratory Architecture.

4.5.1 Ground-Side

4.5.1.1 Center TRACON Automation System (CTAS)

CTAS (see Figure 9) provided ATSP automation tools for planning and controlling air traffic. CTAS generated air traffic advisories designed to increase fuel efficiency, reduce delays, and provided automation assistance to air traffic controllers in achieving acceptable aircraft sequencing and separation as well as improved airport capacity (Sanford, Smith, Lee, & Green, 1999).

CTAS's Active Final Approach Spacing Tool is designed to assist terminal controllers in assigning aircraft to runways, as well as to sequence and schedule aircraft onto the final approach.

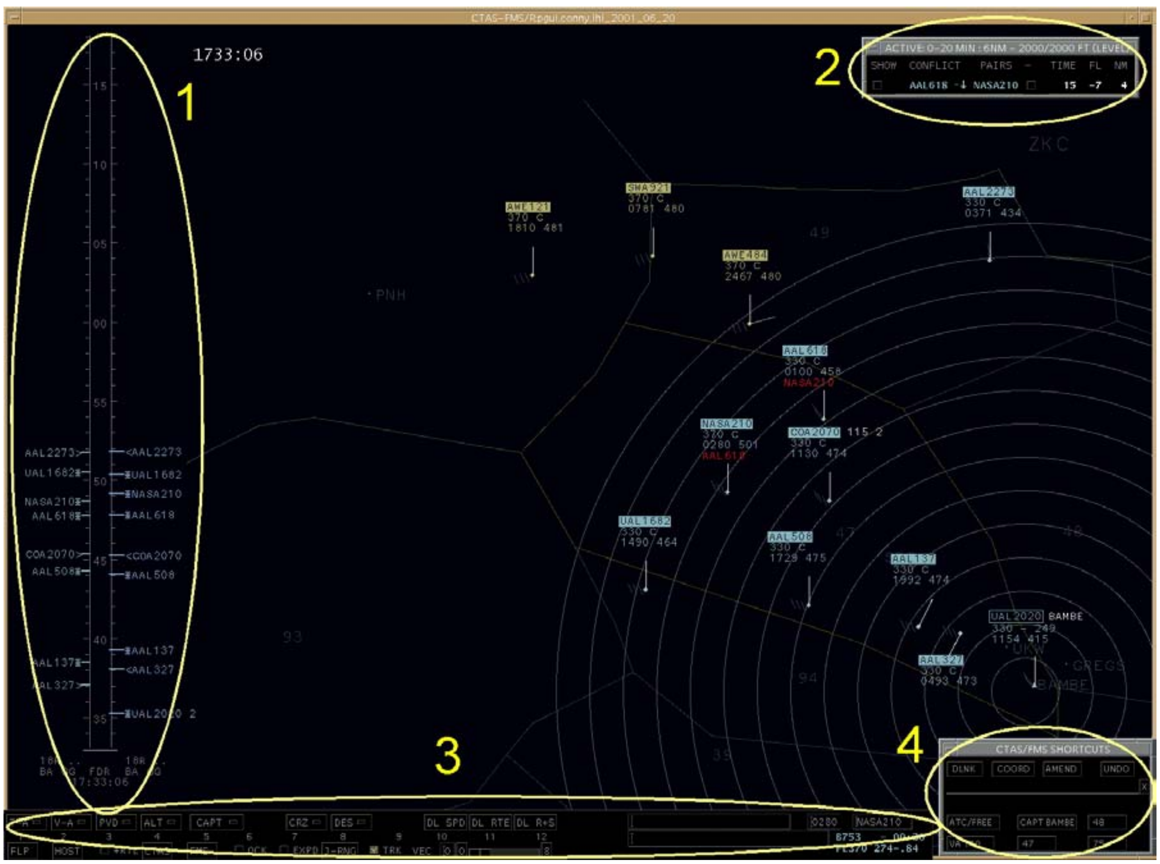

Figure 9. The CTAS Traffic Display Illustrating the Major Components. 1) The Timeline, 2) The Conflict Alert Window, 3) The Toolbar, and 4) The Shortcut Window.

4.5.2 Air-Side Equipment

The Advanced Concepts Flight Simulator (ACFS) was configured as a generic commercial transport aircraft, equipped with an array of advanced flight deck tools including touch-sensitive screens, a heads-up display, and pitch/roll axis sidesticks.

Figure 10 shows the ACFS flight deck, CDTI displays, and outside view (upon touchdown).

Figure 10. Advanced Concepts Flight Simulator with CDTI.

4.5.2.1 Cockpit Display of Traffic Information (CDTI)

The CDTIs (one each for the Captain and First Officer) installed in the ACFS displayed surrounding aircraft up to a range of approximately 160nm. Conflict detection and alerting was enabled, based on probabilistic algorithms and a look-ahead time of 15 to 18 minutes. The RAT was available to flight crew for the planning and execution of route modifications to avoid conflicts in free flight, and for route modification designed to provide for increased efficiency and/or the meeting of crossing times. The CDTI also incorporated new features, unique to, and designed specifically for the demonstration. These included the following:

- Route down-linking to ATC (information-only in free flight) and receipt of up-linked ATC routes for flight crew consideration / implementation, and
- In-trail approach spacing algorithm incorporation with associated display elements, and manual or auto-throttle control-loop options (see Figure 11).

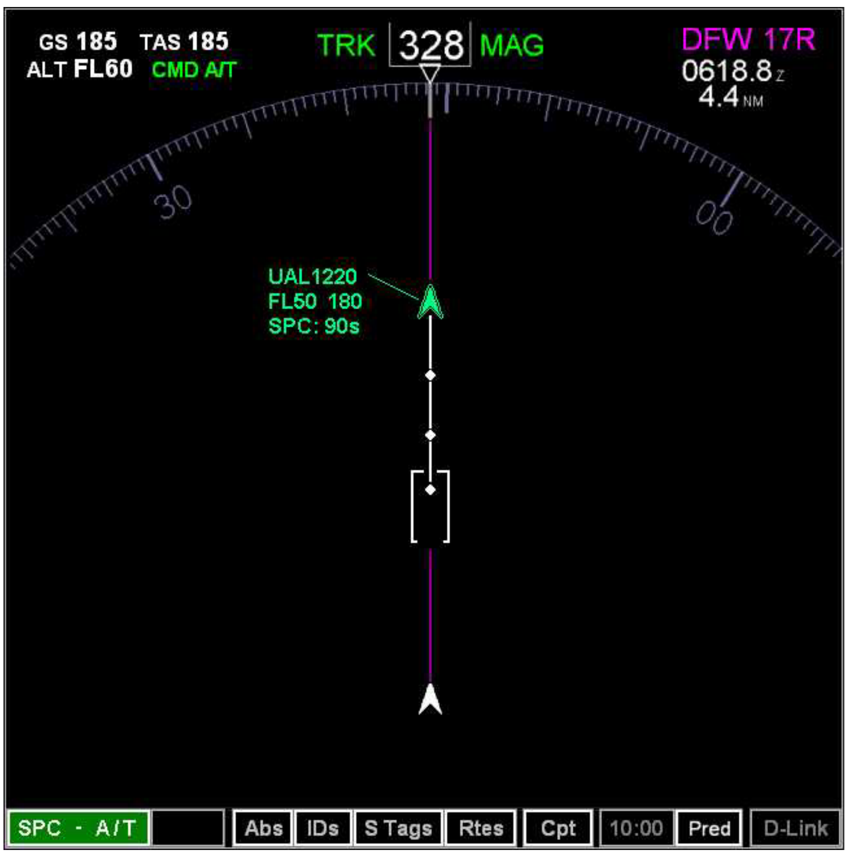

Figure 11. CDTI Showing Initiation of the Spacing Functionality.

4.5.2.2 Flight Deck Display Research Laboratory (for Static Simulator Pilots)

Two single-pilot, simulator stations, each equipped with PC-Plane (see Figure 12) and a CDTI display, were used in the Flight Deck Display Research Laboratory. For the September concept demonstration, a confederate pilot operated one of these stations.

Figure 12. Static Simulator PCPlane Interface- Data link message window is the module right of the Mode Control Panel.

5 Data Collection

As the activities undertaken in September were a technology and concept demonstration only, data collection was limited to questionnaires and debriefings. Participant pilots and controllers completed questionnaires after each scenario run, and at the conclusion of the demonstration as a whole. The questionnaires addressed issues related to usability, workload, situation awareness, information needs, DSTs, and the procedures used during the various CE 5/11 and CE 6/11 scenarios.

6 Schedule

Table 1 shows the daily schedule that was followed for the demonstration.

Table 1. Daily Schedule.

Time	Description
Day 1	**Monday, September 17, 2001**
0800-0900	Briefing
0900-1200	Training
1200-1300	Lunch
1300-1400	45 minute Familiarization Scenario
1400-1600	Scenario 1 (CE 5 Easy)
Day 2	**Tuesday, September 18, 2001**
0800-0830	Discussion on Scenario 1
0830-1030	Scenario 2 (CE 5 Difficult)
1030-1130	Discussion on CE 5
1130-1230	Lunch
1230-1400	Training on CE 6
1400-1600	Scenario 3 (CE 6 Easy – Scenario was done but no questionnaire data was collected due to time limitations.)
Day 3	**Wednesday, September 19, 2001**
0800-1000	Scenario 4 (CE 6 Difficult)
1000-1130	Discussion (CE 6)
1130-1230	Lunch
1230-1600	Demo

Although data collection was planned for all scenarios, due to scheduling constraints data for only three scenarios (except for CE 6 easy scenarios) were collected.

7 Results and Discussion

The results are based on questionnaire and debriefing data. The results are categorized based on procedural considerations, usability of the DSTs, and human performance issues.

The comments noted below are based on a very limited participant pool, are largely anecdotal as a consequence, and therefore limited in their scope.

7.1 Procedural Considerations–Ground Side

Participant controllers suggested the following procedural considerations:

1. FL330 and above should be free flight airspace. All aircraft in this airspace should self-separate.
2. The free flight airspace would be exclusionary, and there should be no mix of aircraft (self-separating vs. managed) with the exception of emergency aircraft.
3. In case of an aircraft emergency situation, the controller would advise all free flight aircraft to maintain their current flight plan and altitude due to an emergency. In other words, free flight operation will be on temporary hold until

the emergency is cleared at which point the controller would advise free flight aircraft to resume own navigation in free flight airspace.

4. A high altitude sector would be created from FL240 (or FL200) to FL280. This sector would serve as the transition airspace between free flight and positive ATSP control (assuming free flight remains at FL290 and above).
5. The transition sector controller would clear aircraft to enter into controlled airspace. Possible phraseology would be "UAL123 cleared to enter controlled airspace via direct to Bowie, Bowie F2 arrival to DFW Airport. Descend at pilot's discretion, maintain FL240."
6. Once an aircraft receives clearance to enter controlled airspace, that aircraft should not deviate from the flight plan without first notifying the controller.
7. The transition sector controller would hand-off to a lower altitude sector controller or to a free flight controller at higher altitude sector. A possible phraseology for transitioning an aircraft from a positive ATSP control to free flight sector would be "AWE567 cleared into free flight airspace climb and maintain FL290."
8. The controller should ensure that any transitioning aircraft are clear of traffic when entering free flight airspace.
9. The lower altitude sector would be at 11,000 feet to FL230. The low altitude sector controller would issue the arrival route altitude restriction. A possible phraseology would be "AAL5 cross BOWIE at one-one thousand. DFW altimeter 29.92."

Several issues were identified which are described below:

1. The procedures for holding aircraft in free flight airspace need to be addressed.
2. The controller may not be actively controlling aircraft in free flight airspace, thereby possibly monitoring with reduced situation awareness. In such a situation, it may be difficult for the controller to take over aircraft separation responsibilities (i.e. at short notice; in an emergency). Therefore, consideration must be given to maintaining controller situation awareness.
3. There should be cues on pilot and controller displays to indicate when an aircraft is in free flight (self separating), transition, or controlled airspace (under positive control).
4. Since CE 11 self-spacing operations required that pilots change speeds to maintain specified spacing behind an aircraft, the pilots should be allowed to deviate from present charted approaches as necessary.
5. During a self-spacing operation, it is important to predict when a potential separation loss would occur and who should be responsible to resolve such a situation. CE 11 self-spacing on approach procedures needs to be expanded on, such that they clearly encompass off-nominal circumstances.

In CE 5 operations, ATSP participants reported a dislike of mixed control in free flight airspace. In one case, confusion over separation responsibility resulted from an arrival aircraft that requested a descent while still in free flight. Separation responsibility was also unclear for traffic at FL280.

7.1.1 Procedural Considerations – Air-Side

The following procedural considerations were derived from pilot comments:

1. An overall comment from the pilot participants was the need to clarify pilot flying (PF) and pilot not flying (PNF) responsibilities for both CE 5 and 6 operations. An increase in DST use such as the spacing aid on the CDTI may increase the need to clearly distribute responsibilities within the cockpit. One suggestion was that the PF monitor aircraft and communicate with the ATSP, while the PNF executed route changes and spacing entries.
2. For CE 6 operations, pilots preferred not to advise ATSP on a problem being solved; instead they suggested that they resolve the conflict and then inform ATSP of resolution via datalink.
3. Pilots expressed a desire to receive a descent clearance either before or as soon as ATSP took positive control. Pilots also suggested allowing aircraft to begin the arrival descent while in free flight prior to ATSP positive control, which is similar to the controllers' suggestion for transition airspace.
4. Pilots reported that they assumed they were in free flight until they received an ATSP cancellation.
5. The pilots indicated that they prefer to have a verbal and/or displayed indication of free flight cancelled (or ATSP positive control being resumed).
6. Interestingly, the pilots were split in their preference for CE 5 or CE 6 operations. One pilot preferred CE 5 because of less interaction with the ATSP and more freedom for changes. The other pilot preferred to rely on ATSP's expertise in separating aircraft.

Overall, pilots reported that CE 11 self-spacing operations were successful and they could follow an ATSP assigned time interval.

For CE 5, CE 6, and CE 11 operations, pilots suggested the following changes to the FMS:

- Display a fix time in hrs:mn:sec on the progress of route data.
- Display a SEND button for route change requests. These may be sent to ATSP and then ATSP sends a route to LOAD. The pilot would then execute the new route indicating cockpit agreement.

7.2 CDTI Usability

In general, the pilots indicated that the CDTI interface was very easy to use. The following feedback was obtained about the CDTI. These comments should be taken as indicative rather than conclusive due to small sample size.

CE 5 and CE 6 operations

- Minimal effort was required to display surrounding traffic and to detect conflicts.
- Conflict detection was possible even before an alert was presented for CE 5 operations, whereas it was difficult for CE 6 operations. This is interesting finding. The possible reason for such difficulty in CE 6 operations is that it required increased communications (for intent and trajectory negotiations) with the ATSP, which may have reduced the available time for conflict detection.
- The conflict alerts provided adequate time for maneuvering.
- Workload involved to detect and resolve conflicts was acceptable.
- CDTI was found to enhance traffic situation awareness, an essential component of free maneuvering.

CE 11 Operations

- CDTI aided the determination of spacing from the traffic to follow.
- Minimal effort was required to use the box to keep adequate spacing from the lead aircraft.
- The selected target feature was used to identify other traffic or traffic to follow.
- Graphical closure indicator did not provide sufficient detail to depict separation trends. One pilot felt that adding a speed trend line would be beneficial.

Interface Considerations -- The colors used to code the traffic symbols were agreed to be appropriate and found to be consistent with other flight deck displays. Symbology was familiar because it was similar to the Traffic Alert and Collision Avoidance System (TCAS), and was as useful or better than TCAS. Some problematic issues were identified, including: difficultly with color discrimination, difference in thickness of the lateral routes on MAP and ND, and disappearance of heading track after 10 sec.

Features -- Information in the data tag and selected target block was easy to understand and the traffic altitude information (particularly pressure altitude) was easy to understand. One of the issues was that when a vector track was on and an aircraft was in a turn, the actual flight paths of the turning traffic and that displayed on the CDTI were different.

Control Panel -- It was easy to use. The labels on buttons clearly identified the function. The key spacing and size were appropriate for accurate use, and the feedback while depressing a key was adequate. A roller ball type mouse was preferred. Specific issues with the control panel include: inputs that required button cycling were not necessarily easy, there were too many steps in approach spacing, and it was difficult to remember left and right button clicks.

Location and Readability --The interface was agreed to be conveniently located and the reach required was acceptable. The display icon size of own aircraft and other traffic was adequate and the readability of the text was adequate.

7.2.1 Overall CDTI Characteristics

The general feedback about the tools, in spite of a few recommended changes, was that it was an excellent aid for conflict detection and resolution in the en route free flight phase as well as controlled flight phase. It was agreed to be an excellent aid for self-spacing and a good situation awareness tool. There were concerns about the high amount of heads-down time necessitated by the use of the CDTI and that the interface was not very intuitive and needed training to be used in real time.

The additional design recommendations included having vivid and bolder colors and reducing button presses for datalink messages. Also, a recommendation was made to change traffic symbols to white on the MCP. Operational recommendations included identifying roles of PF and PNF, making altitude change the same as speed change, and making a flight level change available on flight director and point of approach.

7.3 Human Performance Considerations

Both the controllers and the pilot provided ratings of physical workload, mental workload, overall workload, and situation awareness on a five-point interval scale (1 is very low, 3 is medium, and 5 is very high). Table 2 summarizes the mean ratings of both the controllers and the pilots under the CE 5 Easy, CE 5 Difficult, and CE 6 Difficult conditions. The standard deviation is provided in brackets.

Table 2. Controller and Pilot Mean Workload Ratings.

	Controller Ratings (N=4)			**Pilot Ratings (N=2)**		
	CE 5 Easy	**CE 5 Difficult**	**CE 6 Difficult**	**CE 5 Easy**	**CE 5 Difficult**	**CE 6 Difficult**
Physical Workload	$M = 2.3$ (0.95)	$M = 3.0$ (1.15)	$M = 3.3$ (0.95)	$M = 2.5$ (0.70)	$M = 1.8$ (0.35)	$M = 2.5$ (0.70)
Mental Workload	$M = 2.8$ (0.5)	$M = 3.5$ (1.29)	$M = 3.3$ (0.95)	$M = 2.8$ (1.06)	$M = 2.3$ (0.35)	$M = 2.5$ (0.70)
Overall Workload	$M = 2.3$ (0.50)	$M = 3.3$ (1.50)	$M = 3.3$ (0.95)	$M = 2.8$ (1.06)	$M = 2.3$ (0.35)	$M = 2.5$ (0.70)
Overall Situation Awareness	$M = 3.8$ (1.89)	$M = 4.0$ (1.41)	$M = 4.3$ (0.95)	$M = 3.5$ (0.70)	$M = 3.8$ (0.35)	$M = 3.5$ (0.70)

The physical workload received moderate ratings from both the controllers and the pilots under all the conditions. For controllers, as expected, CE 5 Difficult and CE 6 Difficult had higher physical, mental, and overall workload ratings than CE 5 Easy, likely due simply to the higher traffic levels present.

For pilots, the CE 5 Difficult condition had lower physical, mental, and overall workload than CE 5 Easy. This is interesting and perhaps could be attributed to learning effect since the CE 5 Difficult scenario was completed after CE 5 Easy. Alternatively, traffic density may not have the same effect for FC workload as it is for the ATSP. As expected, CE 6 Difficult resulted in a higher pilot physical, mental, and overall workload as compared with CE 5 Difficult. This higher workload is attributed to increased communications with controllers for trajectory negotiation and intent information.

Situation awareness was moderate or higher for both controllers and pilots in all conditions.

Figures 13 and 14 illustrate the controller and pilot average ratings of the measures under all the conditions.

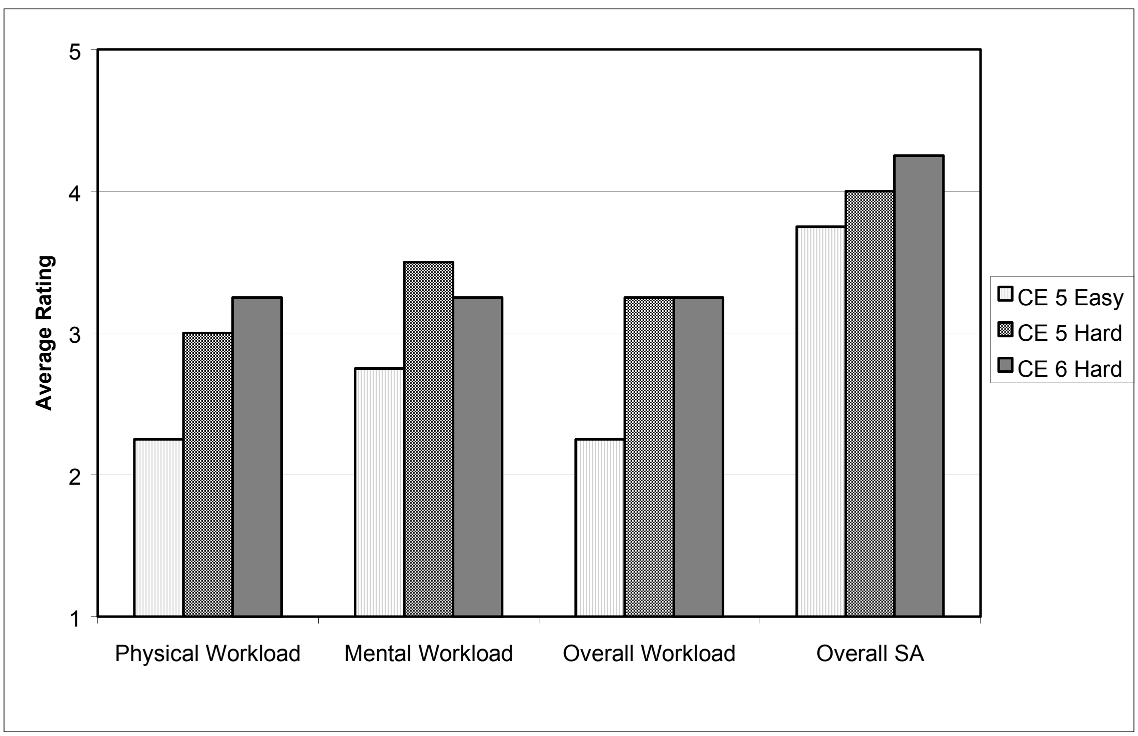

Figure 13. Average Controller Workload and Situation Awareness Ratings.

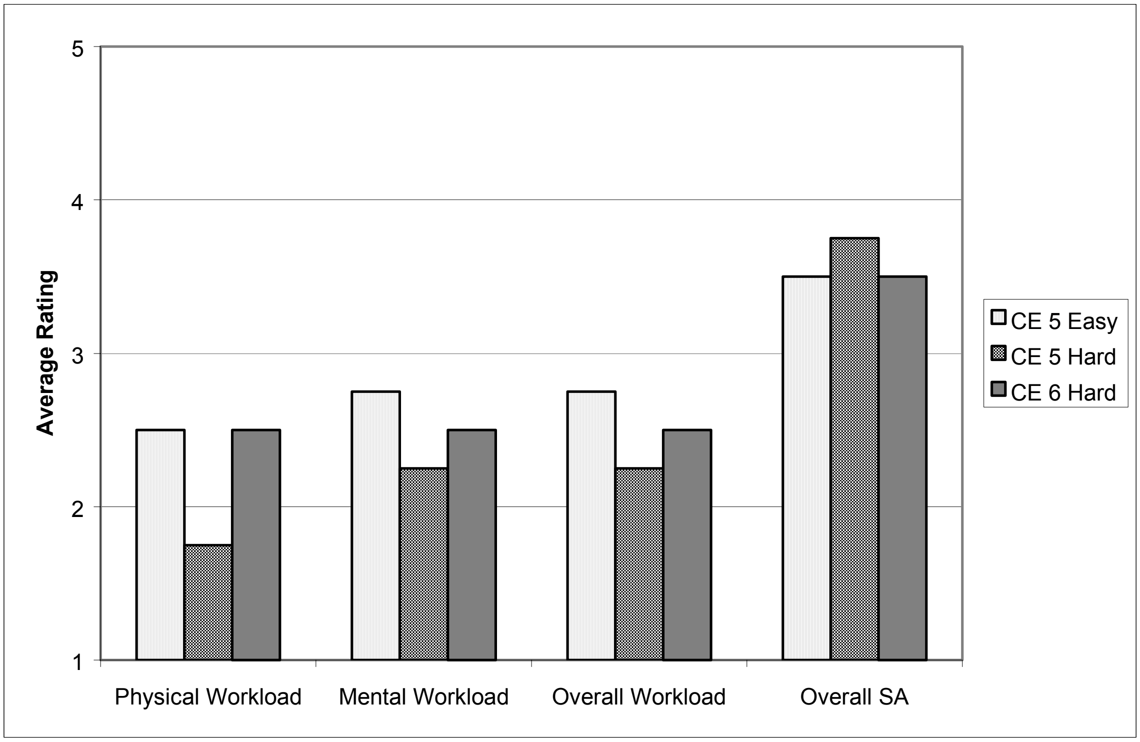

Figure 14. Average Pilot Workload and Situation Awareness Ratings.

7.3.1 Events Affecting Overall Workload and Situation Awareness

Table 3 summarizes the comments collected from the controllers and pilots about events during the scenarios, which may have affected their overall workload and situation awareness.

Table 3. Controller and Pilot Comments.

	Controller Comments	Pilot Comments
Overall	• Interface with three mouse buttons resulted in a higher physical workload. • Automation might help in reducing mental workload.	• The use of automation tools increases comfort levels. • Situation awareness decreased during the use of spacing tool during CE 11 operations.
CE 5 Easy	• N/A.	• Use of spacing tool (CE 11) demands attention. • Ensuring proper arrival time before ATSP cancelled free flight.
CE 5 Difficult	• Unresolved conflict with an aircraft. • Overflights in the free flight and non-free flight airspace.	• Finding the correct aircraft in the spacing tool. • Route changes and spacing tools demand attention and might increase workload. • Concerns about automated speed control.
CE 6	• Aircraft choice of separation not	• Notifying the ATSP of a pending

	Controller Comments	Pilot Comments
Difficult	preferred increasing negotiations.	request for a route change. • Automated route changes should be displayed on the ATSP screen prior to execution. • Heads down time was high and might negatively affect situation awareness.

8 Conclusions

Overall, the technology and concept demonstration was successful. The following is a summary of the results and findings:

1. The DAG-TM team successfully developed a technical infrastructure to conduct ongoing DAG-TM research. This will be very beneficial for further studies.
2. The demonstration was based on a *build a little, test a little, and demonstrate a little* principle. This proved very beneficial as procedural and DST characteristics were iteratively improved while developing the demonstration.
3. The subjective feedback from controller participants reinforced a need to conduct further research related to procedures, particularly with regards to transitioning between free maneuvering and controlled airspace.
4. Both the controllers and pilots indicated that cues that distinguish free maneuvering, transitioning, and self-spacing aircraft would be beneficial.
5. Overall CDTI and CTAS DSTs were helpful and supported the CE 5, CE 6, and CE 11 operations. A few DST features may need further refinement.
6. Based on this preliminary demonstration, both controller and pilot comments indicate the concepts to be feasible. However, further examination related to transitioning from free flight to controlled flight airspace is necessary. There was no unanimous consensus among pilots on a preference for CE 5 or CE 6.

This demonstration did not include a baseline, control test condition, or different traffic flows and weather conditions, and was based on a very small sample size. Therefore, findings must be interpreted with caution. Primarily, the study demonstrated the technological capabilities, information displays, and basic procedures that support the concepts rather than the systematic assessment of their benefits.

9 Further Research

The participant feedback and DAG-TM researchers input indicated that further research is needed to address the following:

1. Complex traffic conditions that include a mix of overflights, transitioning aircraft, arrivals and departures,
2. Different airspace configurations (e.g., size and altitude strata) for transitioning aircraft between free maneuvering and controlled airspace,

3. More realistic conflicts that include conflicts spread throughout the scenario, conflicts involving more than two aircraft, simultaneous conflicts, and successive conflicts for the same aircraft,
4. A more realistic trajectory negotiation process where ATC and flight crew iteratively develop mutually acceptable aircraft route changes,
5. Inclusion of weather and special use airspace that will constrain aircraft routes and require additional negotiations,
6. Consideration of airline priorities, and AOC involvement in required time of arrival sequencing and route changes, and
7. Different aircraft equipment mix with CDTI and non-CDTI equipped aircraft.

Further studies should include extensive data collection to address the feasibility and benefits of the concepts.

Acronyms

AATT	Advanced Air Transportation Technologies
ACFS	Advanced Concepts Flight Simulator
ADS	Automatic Dependent Surveillance
AOC	Airline Operations Center
ARTCC	Air Route Traffic Control Center
ATC	Air Traffic Control
ATSP	Air Traffic Service Provider
CD&R	Conflict Detection and Resolution
CDTI	Cockpit Display of Traffic information
CE	Concept Element
CTAS	Center TRACON Automation System
DAG-TM	Distributed Air/Ground Traffic Management
DST	Decision Support Tool
FC	Flight Crew
FMS	Flight Management System
IMC	Instrument Meteorological Conditions
NAS	National Air Space
PF	Pilot Flying
PNF	Pilot Not Flying
RAT	Route Assessment Tool
RTA	Required Time of Arrival
SUA	Special Use Airspace
TCAS	Traffic Collision Avoidance System
TFM	Traffic Flow Management
TMU	Traffic Management Unit
TOD	Top of Descent
TRACON	Terminal Radar Approach Control
VMC	Visual Meteorological Conditions
VNAV	Vertical Navigation
ZFW	Dallas Fort Worth ARTCC

References

Advanced Air Transportation Technologies (AATT) Office. (1999). *Concept Definition for Distributed Air/Ground Traffic Management* (DAG-TM) Version 1.0, Moffett Field, CA: NASA Ames Research Center.

Couluris, G. J. (2001). *Detailed Description for CE-6 En Route Trajectory Negotiation.* (Contractor Report NAS2-98005 RTO-41). Los Gatos, CA: Seagull Technology, Inc.

Philips, C. T. (2000). *Detailed Description for CE-5: En route free maneuvering* (NAS2-98005 RTO-41). Billerica, MA: Titan Systems Corporation.

Sanford, B. D., Smith, N., Lee, K., & Green, S. (1999). *Decision-aiding Automation for the En Route Controller: A Human Factors Field Evaluation*. Presented at the Tenth International Symposium on Aviation Psychology. Columbus, OH.

Sorensen, J. A. (2000). *Detailed description for CE11. Terminal arrival: Self-spacing for merging and in-trail separation* (NAS2-98005 RTO-41). Los Gatos, CA: Seagull Technology, Inc.